

Influencing driver behaviour through road marking

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Abstract

This paper will describe how road marking can be used to influence driver behaviour in order to improve road safety and traffic flows. Extensive use will be made of examples from recent research undertaken by the authors on overtaking lane design, speed change management, managing speed around curves and improving the safety of high risk sections of roads. This research included both on-road and driving simulator-based measurements. The concept of self explaining roads and what is required to implement it will also be described.

Driving task

In describing the influence of road marking on driver behaviour it is important to first consider the core driving task. Driving involves a sequential process of perceiving and making sense of the situation, deciding on how to best respond given the driver's knowledge and goals, and taking some action. That action, for example a steering input or brake application, results in the vehicle responding which in turn changes the situation the driver now perceives and reacts to. This Perception-Decision-Action (PDA) cycle, shown in figure 1, emphasises the dynamic essence of the driving task; a continuous, manual-control feedback loop guided by the momentary perceptions, decisions, and actions of the driver (Charlton & Baas, 1998). The cycle time of the feedback loop depends on a range of slower-changing state parameters of the various components including: vehicle performance; road and traffic conditions; driver situation awareness and mental workload.

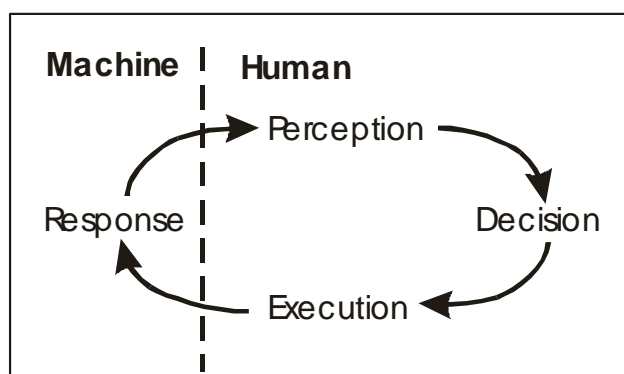


Figure 1: Perception-Decision-Action Cycle

Perception

There are some key limiting factors to the efficiency and accuracy of the driver's performance in the PDA cycle. At the perception stage of the cycle, for example, a driver's foveal vision (where there is the greatest acuity) is limited to a concentrated cone of 2 to 4 degrees even though overall perception is wide. This means that the driver must scan the environment focussing on specific items such as the side of the

road, road signs and the dashboard much like a torch. Although information may enter the driver's perception in ways other than foveal vision (e.g., road noise, kinaesthetic sensation, or peripheral vision), it has been estimated that as much as 90% of the information drivers use when they drive comes from primary visual cues. Studies of eye movements while driving have found that fixations range from 1/10 to 1/3 second for checking lane position and longer glances of up to 2 seconds or more to read a sign or to estimate whether there is a sufficient gap to cross traffic. At open road speeds (100 km/h) there may be a significant change in the road or traffic situation in a 2-second period, the vehicle having travelled 56 metres further down the road.

A wide range of visual information including the position and behaviour of other vehicles and pedestrians, road condition, state of the vehicle being driven, in addition to external information sources required for secondary tasks such as route planning and navigation, need to be processed by the driver. The driver's attention is limited, however, and the amount of attention required for the core driving task varies with the complexity of the driving situation and the need to attend to any of a number of competing demands. In high workload situations that involve secondary tasks (such as talking on cell phones) less attention may be directed towards driving, and hence there is an increase in risk of a crash occurring. Very low workload situations that result in boredom, such as driving on very familiar routes, can also result in a reduction in attention directed to the driving task as attention is directed towards other things such as inner-thoughts or looking at the scenery, pedestrians or other traffic that are not relevant to the driving task at hand.

Decision

At the decision stage of the PDA cycle, the information attended to and perceived by the driver (only a small subset of the information available in the situation) is used to make sense of the situation, and make decisions about the actions required. For highly-practised drivers on familiar routes, the decision-making process may take the form of recognition-primed decisions or "habitual procedures". In these cases, very few cognitive resources are required to recognise the situation as familiar and then automatically select the appropriate (highly-practiced) action. For drivers with less experience, or drivers in an unfamiliar setting, the decision-making process is not automatic, the situation must be actively comprehended and alternative actions consciously evaluated according to learned rules and heuristics.

Action

For the action stage the experienced driver has many well-learned "motor programs" available, and once selected, they can be executed with very little requirement for progress monitoring or error correction. Drivers with less skill or experience, however, may be required to devote considerable attention to the progress of their actions, fine-tuning and correcting them throughout their execution. Clearly, the greater the level of skill of the driver, the greater their ability to perceive the situation, process the information, and act appropriately. However driving is not just a skills-based task, it also involves learning the rules (both formal and informal) that require some restraint to personal preferences that may lead to immediate gratification in the interests of the safety of others.

Interaction of vehicle, road and driver factors

How well the core driving task is performed is dependent on the performance of the vehicle, the design and condition of the road, the presence of other traffic and the driver's beliefs and attitudes. This is shown diagrammatically in figure 2. Broadening the systems perspective beyond the core driving task it can be seen that many of these factors interact with one another to influence the performance of the PDA cycle. For example the ability to negotiate a curve is dependent on the geometry of the road and its surface texture, visual characteristics of the curve and road markings, the stability and condition of the vehicle, the driver's experience with curves and the driver's attitudes (including beliefs about their own driving skill).

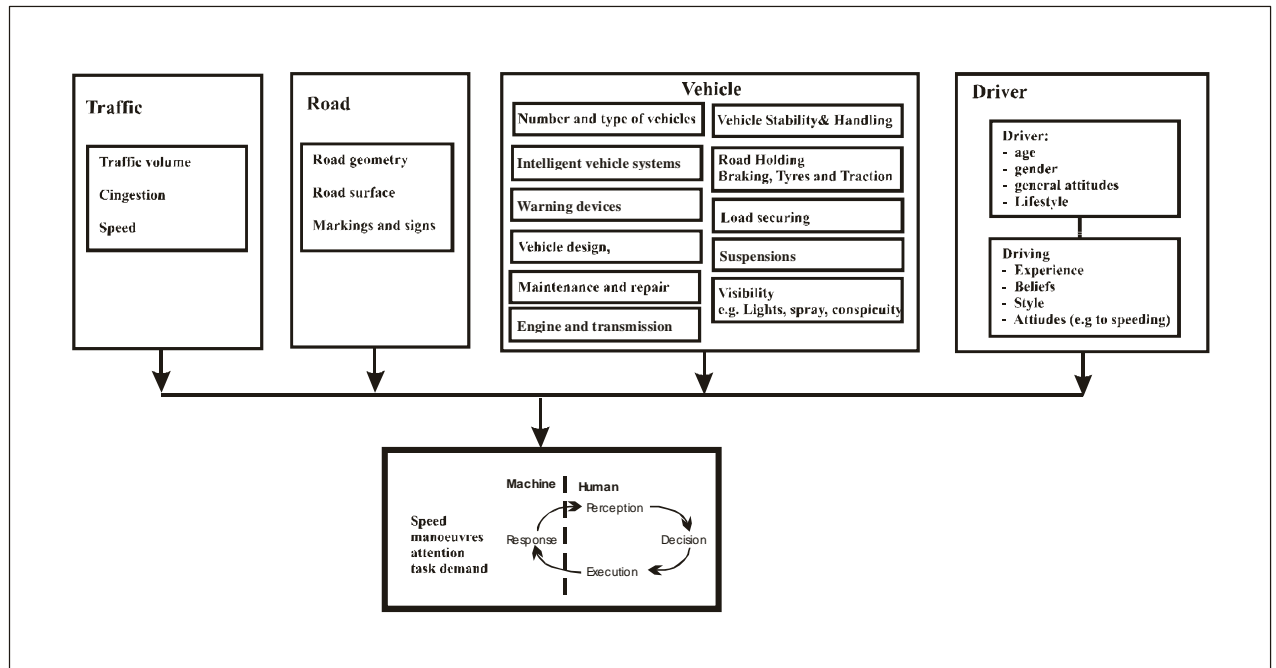


Figure 2: Vehicle, road, driver and traffic conditions as contributing factors

Some traffic control devices and road safety treatments are designed to provide information to drivers by means of an explicit alerting function. For example, speed limit signs and many hazard warning signs are designed to direct drivers' attention to road or traffic conditions and undertake recommended or required driving behaviours; the information is explicit as it relies on a driver consciously attending, comprehending, and responding to the information. In contrast, some treatments are designed to work at an implicit, or perceptual level, by affecting drivers' perception of their speed without conveying an explicit or specific message. For example, transverse road markings and lateral edge line treatments have been implemented at many locations overseas to reduce vehicle speeds by modifying the visual information used to perceive speed subconsciously (Fildes & Jarvis, 1994). The desirability of road safety treatments based on implicit perceptual cues lies in their unobtrusiveness; they do not place any additional processing demands, distractions, or frustrations on the driver, they do not involve introducing any additional hazards on the roads, and in some cases they may be the only way to influence drivers who refuse to obey the law.

In practical terms, driving down a narrow road, a road lined with hedgerows, or through a tunnel, is often accompanied by an exaggerated sense of speed. Driving

situations with reduced edge-rate information, such as open highways with broad lanes and shoulder widths are frequently associated with lower perceived speeds (Fambro, Turner & Rogness, 1981; Smiley, 1997). This phenomenon, mathematically and conceptually characterised as an optic flow pattern, has been the basis for a range of road treatments designed to reduce drivers' speeds by perceptually increasing their apparent speed (Fildes & Jarvis, 1994; Godley, Fildes, Triggs, & Brown, 1999). These treatments, known as perceptual countermeasures, have employed painted transverse lines, chevron markings, and enhanced edge lines to decrease apparent lane width and increase apparent speed. Perceptual cues such as these appear to function at an implicit or "automatic" level in the sense that drivers need not explicitly attend to them or consider their meaning in order for them to be effective.

Self explaining roads

Road safety researchers and road controlling authorities in many countries have identified inadvertent speeding (where motorists are unaware that they are exceeding the speed limit) as a significant safety issue. Speed is a well-documented cause of crashes for New Zealand drivers, with high speeds and speed variability being associated with increased probabilities of crashes and serious injuries. Historically, the most common method of alerting drivers to stay within a designated speed has been through the use of road signs. The placement and design of road signs has a good history of research and there are a number of well-established standards for their size and placement. Unfortunately, research indicates that road signs are noticed and recalled by a relatively low proportion of drivers. An alternative approach for bringing drivers into compliance with a desired speed has been to introduce physical restrictions or "forcing functions" that make it difficult or unpleasant to exceed the designated speed. Some of the earliest attempts at introducing speed management through physical restrictions occurred nearly 30 years ago in the Netherlands and Germany where measures such as chicanes, speed humps, neck downs, planters and other traffic calming devices were added to the streetscape to reduce motor vehicles' speeds in residential areas and villages. Although these traffic calming techniques frequently have an immediately beneficial effect on speed change, they can be viewed quite negatively by road users.



A chicane & speed hump treatment in the United Kingdom.

Because drivers will select alternative routes to avoid speed management treatments based on physical restrictions, localised traffic calming strategies have been replaced by an area-wide traffic calming or speed management approach in some countries.

Area-wide speed management relies on a substantially greater variety of treatments than the original physically restrictive speed humps, chicanes, and street closures. Unlike the earlier localised traffic calming initiatives, the goal is not just to reduce speeds, but instead to manage speeds in a sustainable way by making use of physical interventions, visual treatments, and drivers' own learned driving habits. This approach, known variously as sustainable safety, self-explaining roads, or self-enforcing roads, is based on the psychological finding that with repeated exposure to similar situations, people develop mental scripts (schemata) which help them to anticipate likely events and produce appropriate responses. With extended practise, scripts and schemata even allow people to perform complex tasks more or less automatically, without explicit or conscious attention to the task. As with other well-practised behaviours, a considerable proportion of vehicle control actions may be performed automatically while driving. The self-explaining roads approach recognises this situation and promotes road designs that assist drivers in forming appropriate schemata for various categories of road (including the desired speed), promoting successful categorisation, and as a result, correct behaviour for that road.

Self-explaining roads are designed to include specific geometric, marking, paving, and roadside elements that can be readily used by drivers to categorise road types and serve as implicit (unconscious) controls on driver behaviour. For example, the Netherlands' Sustainable Safety programme involves identifying a set of desired road functions (through roads, distributor roads, and access roads), then identifying road designs that produce the desired operating speed for each road function, and finally applying those road designs consistently to all roads having the same function. The result is that roads with the same operating speed look very similar to one another while roads with different operating speeds look quite different from one another.



Three different road functions in the Netherlands' Sustainable Safety programme.

A similar approach is being taken in the United Kingdom where they have developed a Road Hierarchy for Speed Management consisting of three tiers: through roads of national or regional importance; mixed use roads; and local roads. Like the

Netherlands' Sustainable Safety programme, the goal is to make the designated speed environment obvious and acceptable to users through a combination of design features such as road width, road markings, pavement surfaces, and roadside furniture.

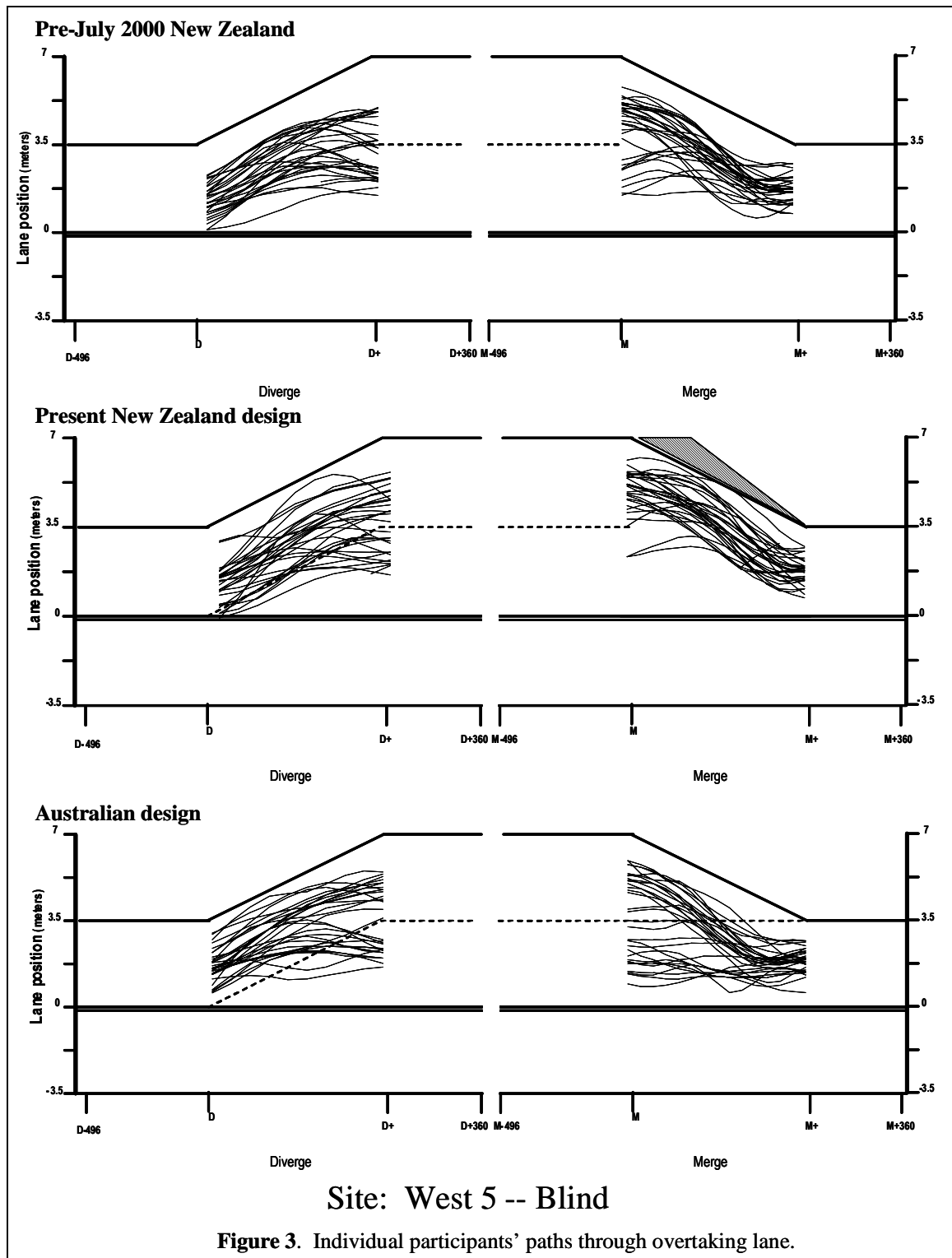
Speed change management

Inadvertent speeding has been identified as a significant safety risk. A study undertaken by Charlton, Alley, Baas, & Newman (2002) examined the relative effectiveness of perceptual and attentional features in the design of urban-rural threshold treatments. The study found that oversized signage significantly reduced drivers' speeds, even when no explicit speed restriction information was present on the signs. The effect of these large unmarked signs, and smaller subsidiary effects for narrow lane markings and traffic islands, was interpreted as an illustration of the effect of implicit perceptual cues in regulating drivers' speeds. However without careful attention to perceptual effects after the threshold, speed can actually increase. For example, there was an 8% increase in the speeds of west-bound traffic after the implementation of a countermeasure at the eastern threshold of Ngatea. Previous research conducted in our laboratory and verified in the field has demonstrated that a contributing factor to these inconsistent effects stems from the perceptual after-effects of thresholds that are sited prior to low-density urban streetscapes (Alley, 2000). Our findings suggest that more effective speed reduction at these threshold sites could be achieved with the inclusion of downstream countermeasures or cues to ensure that speed reductions are maintained. These countermeasures would normally include road markings.

Overtaking lane design

The influence of road markings on driver behaviour can also be clearly seen in overtaking lanes. A Land Transport NZ research project undertaken by TERNZ included both driving simulator and on-road investigations into the effectiveness of overtaking lane designs (Charlton, Alley, Wigmore, Baas, 2001), (Luther, Alley, Charlton, Wigmore, Baas, 2004). The driving simulator trials used the University of Waikato / TERNZ DS9 Driving simulator. On-road measurements included the use of multiple tube counters, speed guns and video recording. The use of the driving simulator has the advantage that the exact track of the vehicle and its behaviour can be recorded and different treatments can be tried without the expense and risk associated with modifying on-road treatments. A validation of the driving simulator found that, especially in terms of speed selection, the behaviour on-road was very similar to that measured by the simulator in both absolute and relative behavioural terms.

Figure 3 shows the tracks taken by the simulator participants for different road marking treatments. The first diagram shows the behaviour pre-July 2000 when there was no diverge line. The second diagram shows the current New Zealand treatment which includes a diverge line that directs the traffic to the left lane. The third diagram shows the Australian treatment which differs from the new NZ treatment by having the centreline extend right through the merge area. The use of the diverge line resulted in more drivers using the left lane. The Australian centreline in the merge area resulted in increased merging activity and slower speeds in the merge area as the slower vehicles in the left lane tried to give way to the faster traffic in the overtaking lane.



A key finding was that the merge areas need to have long taper lengths and be clearly visible from well before merging begins. Merge areas on curve or past the crest of hills should be avoided.

Curve speed

Speed-related crashes are often noted to occur at curves and roundabouts where drivers underestimate their approach speeds and enter the curves or roundabouts at

speeds far in excess of that which is safe. To assist drivers in negotiating curves safely, many curves are posted with warning signs to indicate the direction and approximate degree of the turn required. In addition, many of these curve warnings also have a supplementary plate showing a suggested speed for the curve. In New Zealand, these suggested speeds are between 15 and 95 km/h (and always end in a 5 to differentiate them from speed restrictions which are always an even number). Research has shown, however, that relatively few drivers act in accordance with these suggested curve speeds (Donald, 1998). One study reported that 90% of drivers exceeded the suggested speed and over half exceeded it by 10 to 30 km/h (Chowdury, Warren, Bissell, & Taori, 1998). This is perhaps not surprising in light of the finding that a majority of warning signs may not be noticed by drivers (Hughes & Cole, 1984; Shinar & Drory, 1983). In a study of drivers' attention to warning signs (e.g., cross roads, school crossings, sharp curves, etc.) it was found that only 6% of motorists could recall having seen the target warning signs and only 9% could recognise the correct sign (Drory & Shinar, 1982). A range of other studies have also noted generally low levels of attention and recall for warning signs and have questioned the effectiveness of the current system of traffic and warning signs (Fischer, 1992; Johansson & Backlund, 1970; Macdonald & Hoffmann, 1991; Summala & Hietamaki, 1984). It is interesting to note, however, that of drivers unable to recall a specific warning sign, 39% to 43% did make appropriate vehicle control adjustments prior to passing the sign (Fischer, 1992). This finding has been interpreted as evidence that these drivers slowed down or altered their steering because of the implicit perceptual characteristics of the situation (e.g., a curve with limited clear sight distance, or increased congestion). Further, it has been suggested that a sizeable proportion of warning signs are needed only under conditions of poor visibility; with good visibility, some warning signs are not noticed because they convey information that is redundant with other sources (Drory & Shinar, 1982; Hughes & Cole, 1986).

To explore these issues, we conducted a laboratory experiment comparing three different types of curve warnings across three different levels of curve severity in a driving simulator in order to determine which warnings were the most effective in reducing drivers' curve speeds. The first type of warning was a yellow diamond-shaped PW-17 sign with a black arrow indicating the direction of the curve accompanied by a smaller sign with a suggested curve speed. These diamond warnings were located along the left (driver's) side of the road 64 m prior to the curve. The second type of warning was a black and white RC4 chevron warning sign pointing in the direction of the curve and a suggested speed as an integral part of the sign. In practice, chevron warnings are typically used to indicate more severe curves (often in concert with diamond signs) and serve to perceptually highlight the curve by virtue of their placement directly in front of the driver as they approach the curve. The third type of warning (a road marking warning) consisted of a suggested curve speed painted on the road surface 64 m prior to the curve followed by a series of transverse lines at decreasing intervals, ending 6 m prior to the curve entry (intended to influence drivers' perception of speed).

All of the warnings worked reasonably well for severe curves (45 km/h). For 65 km/h and 85 km/h curves, however, the PW-17 signs were ineffective in slowing participants in the presence of the additional attentional demands of a cell phone task. In contrast, the RC-4 chevron signs and road marking warnings were accompanied by lower 65 km/h curve speeds, even in the presence of cell phone tasks. For the 85

km/h curves, the chevron warning was the most effective, the road marking warning failing to slow participants on these curves during a cell phone rhyming task. It is worth noting that the chevron warnings typically slowed drivers sooner than the road marking warnings. The road marking warnings began 64 m prior to the curve entry, and although the chevron warnings were located past the curve entry, they apparently possessed greater visibility prior to the 64 m curve approach.

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